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Short Communication

Bonding strength of heat treated compressed Eastern redcedar wood

Tuncer Dilik [a,1], Salim Hiziroglu [b,*]

[a] Department of Forest Products Engineering, Faculty of Forestry, Istanbul University, 34473 Bahcekoy, Istanbul, Turkey
[b] Department of Natural Resource Ecology & Management, Oklahoma State University, Stillwater, OK 74078-6013, USA

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ABSTRACT

The objective of this study was to evaluate effect of heat treatment and compression on some properties of Eastern redcedar (*Juniperus virginiana*) including bonding strength, hardness and surface quality. Specimens were exposed to three temperature levels of 120 °C, 160 °C and 190 °C for 6 h before they were compressed using 2.5 MPa pressure for 5 min. Polyvinyl acetate (PVAc) bonded specimens showed 23.6% reduction in their shear strength when they were exposed to a temperature of 120 °C. Such strength reduction values were 44.4% and 64.1% for the specimens exposed to temperature levels of 160 °C and 190 °C, respectively. The lowest average Janka hardness value of 214.08 kg was determined for the samples exposed to a temperature of 190 °C while those treated with a temperature of 120 °C had the highest hardness value of 397.73 kg. It appears that combination of heat treatment and compression enchanced overall surface quality of the samples in the form of their roughness determined using stylus type equipment.

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1. Introduction

Heat treatment of wood and wood products originally has been developed in Europe during 1990s. The main idea behind of heat exposure of wood is to enhance its properties so that it can be used more efficiently and effectively during its service life [1–4]. Thermally treated products manufactured by thermowood (Stellac) in Finland, torrefaction (Perdure) in France and Plato-wood in the Netherlands are some of the examples of this technology [5–8]. It is a fact that temperature over 150 °C permanently alter the physical and chemical properties of wood. Having higher treatment temperature would also enhance biological durability but some undesirable effects of the treatment such as reduction of strength and hardness of wood are inevitable [9]. Thermally treated wood becomes more brittle, and its bending and tension strength characteristics are decreased by 10–30% [4,10]. Therefore, the use of heat treated wood in load-bearing applications is not suggested [5]. It has been found that dimensional characteristics of wood is generally improved as a result of heat treatment. However heat treated wood usually has reduced strength properties [9,11]. The process of heat treatment is combined by breakage of the lignin-polysacharide complex by organic acids released from hemicellulose [12]. Various past studies revealed that progressive degradation of the hemicelluloses between microfibrils is the main mechanism of strength reduction within wood [13]. Removing of side chain hemicellulose components adversely influences strength loss of heat treated wood. Thermal modification of different species has been well established and there are several commercial applications of heat treated wood in various countries in Europe [6]. Mechanical properties of hazelnut wood as function of heat treatment was investigated in a previous study [14]. It was determined that the samples had maximum reduction of 63.94% for hardness when they were exposed to a temperature of 180 °C for 8 h [14]. Overall strength properties of different species treated with a temperature above 150 °C also were adversely influenced based on the findings another past work [15].

Eastern redcedar (*Juniperus virginiana* L.) is one of widely distributed species in Oklahoma. Current area covered by Eastern redcedar in Oklahoma is estimated beyond 4.5 million ha and it is projected to be 6.3 million ha by 2013 [3]. The cedar population is growing at the rate of 380 ha per day resulting in a significant adverse impact on ecology [3,16]. If action is not taken it is predicted that problem caused by Eastern redcedar invasion will cost $447 million by 2013 [16].

A study carried out by Kasemsiri et al. [3] evaluated certain characterization of heat treated Eastern redcedar samples, namely their dimensional stability and shear strength. It was found that dimensional swelling values of the samples exposed to a temperature of 180 °C for 8 h were enchanced [3]. However similar to the results of other previous studies shear strength of heat treated wood specimens had reduction as compared to those of untreated control samples [4].

Various studies investigated properties of different wood species compressed for several minutes in a laboratory press [17–19]. Strength properties of compressed wood have been increased

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* Corresponding author. Tel.: +1 405 744 5445.
E-mail addresses: tuncerd@istanbul.edu.tr (T. Dilik), salim.hiziroglu@okstate.edu (S. Hiziroglu).
[1] Tel.: +90 212 226 1100.

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along with its surface quality resulting in lower adhesive use where it is applicable such as plywood or overlay manufacture.

Both physical and mechanical properties of Eastern redcedar wood have been well established in Wood Handbook [20]. However there is very little information on hardness, bonding strength and surface roughness of heat treated compressed of this species in literature. Therefore, the main objective of this study was to evaluate above properties of Eastern redcedar to establish an initial data so that this species can be used more efficiently and effectively for further manufacturing process.

2. Experimental details

Twenty millimetres thick boards of Eastern redcedar were supplied by a local sawmill in Oklahoma. Each boards were planned and cut into strips with 20 mm width before they were reduced into 50 mm long samples. Defect free samples with tangential grain orientation were conditioned in a room with a temperature of 20 °C and a relative humidity of 65% until they reach to a equilibrium moisture contest of 12%. A total of 32 pairs of samples for control and three heat exposure levels of 120 °C, 160 °C and 190 °C were used for the experiments. Dimensions and weight of each sample were determined at accuracy levels of 0.01 cm and 0.01 gr respectively. Heat treatment of the samples was carried out at three temperatures 120 °C, 160 °C and 190 °C in a laboratory type oven controlled at an accuracy of ±1 °C under atmospheric pressure. Heat treated specimens were compressed on a Carver press for 5 min using a pressure of 2.5 MPa. Fig. 1 shows heat treated Eastern redcedar samples.

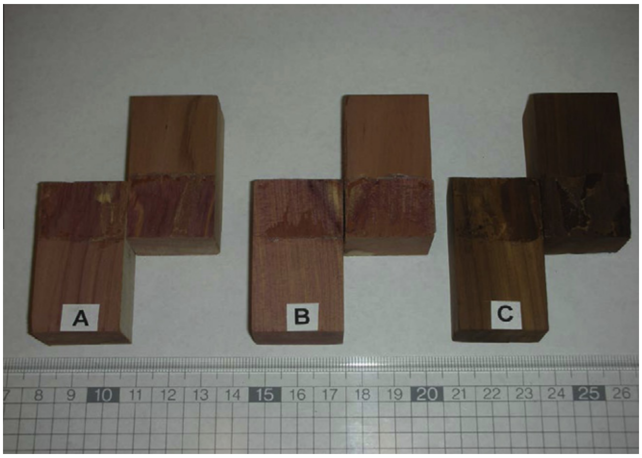

Fig. 1. Heat treated Eastern redcedar samples.

In generally surface quality plays an important role to control amount of adhesive applied to the members of bonding as well as quality of glue line. There are various methods to evaluate surface quality of wood and wood products but stylus method was successfully used to evaluate surface roughness both solid wood and wood composite samples in past studies [21,22]. Six measurements with a tracing span of 15.2 mm were taken from both sides of the samples across grain orientation by employing Hommel T-500 profilometer before and after heat treatment and compression of the samples. Stylus unit used in this study consists of the main unit and the pick up model TkE. The pick up has a skid type diamond stylus with 5 μm tip radius and a 90° tip angle. The stylus traverses the surface at constant speed of 1 mm/s over 15.2 mm tracing length, covering the vertical displacement of the stylus into an electrical signal. The calibration of the instrument was checked every 100 measurements by using a standard reference plate with R_a values of 3.02 μm and 0.48 μm. A cut-off length of 2.54 mm, a parameter that differentiates roughness and waviness profiles from each other was used for the test [10].

3. Results and discussion

Table 1 displays test results for the control and heat treated compressed samples exposed to three temperature levels. Based on the findings in the work bonding strength and hardness of the specimens were adversely influenced due to heat treatment. Compressed control samples had an average bonding strength value of 5.83 MPa which is 23.6% lower than those samples exposed to a temperature of 120 °C. Their bonding strength values further reduced with increasing temperature to 160 °C and 190 °C as illustrated in Fig. 4. In a previous work carried out to determine effect of heat treatment on mechanical properties of eucalyptus (*Eucalyptus camaldulensis* Dehn) also showed reduction of overall strength characteristics of the specimens [23]. Bonding strength of heat treated Eastern redcedar samples without having any compression also resulted in significant reduction when they were exposed to a temperature of 180 °C for 6 h as compared to those of control specimens. In general compression of wood enchances its strength properties due to densification. In this study adverse influence of heat treatment on bonding strength of the samples

Table 1
Test results of the specimens. (Numbers in parentheses and brackets are standard deviation and property reduction values in percent, respectively.)

Test name	Control samples	Heat treated samples		
		120 °C (A)	160 °C (B)	190 °C (C)
Shear strength (MPa)	5.83	4.45	3.24	2.09
	(1.68)	(0.96)	(0.47)	(0.48)
	[0]	[23.6]	[44.4]	[64.1]
Janka hardness (kg)	534.35	397.73	348.99	214.08
	(78.61)	(93.70)	(69.71)	(30.11)
	[0]	[25.5]	[34.6]	[59.9]
Roughness parameters (μm)				
R_a	4.67	4.41	4.35	4.28
	(0.41)	(0.80)	(0.34)	(0.47)
	[0]	[5.5]	[6.8]	[8.3]
$R_{\max}$	43.50	42.08	41.40	33.39
	(5.84)	(6.41)	(5.46)	(3.66)
	[0]	[3.2]	[4.8]	[23.2]
R_z	36.51	35.40	32.65	30.78
	(3.27)	(4.88)	(3.31)	(2.87)
	[0]	[3.0]	[10.5]	[15.6]

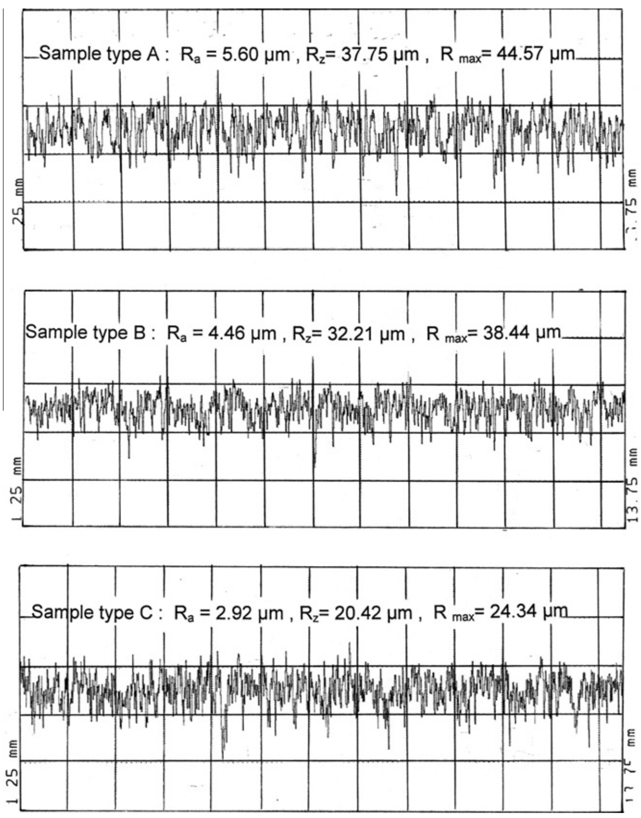

Fig. 2. Typical roughness profiles of the specimens.

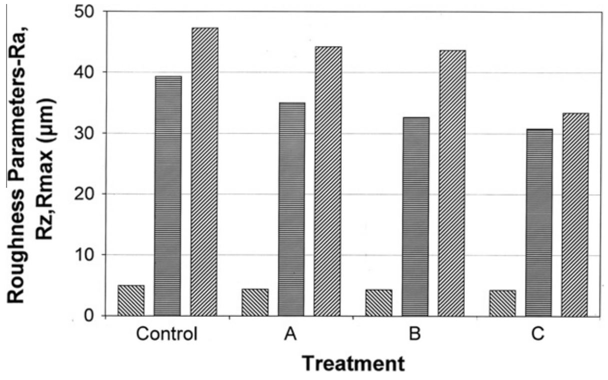

Fig. 3. Average values of roughness parameters.

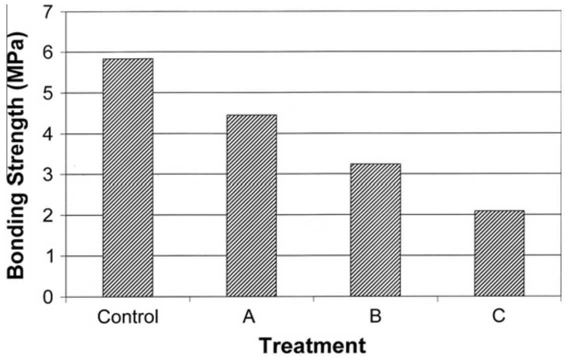

Fig. 4. Average bonding strength values of the samples.

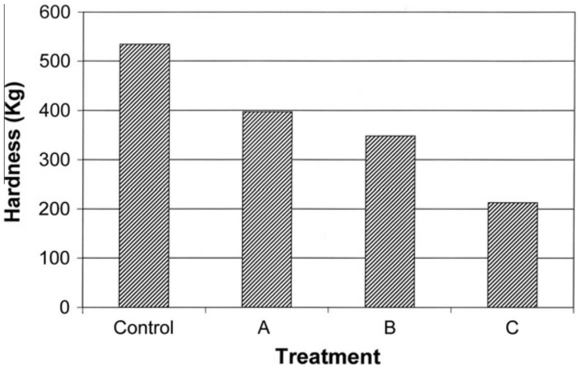

Fig. 5. Average hardness values of the samples.

was reduced by their compression. It is possible that if no compression was applied to the specimens their strength values would be lower. Comparable results were also determined in a past study carried out on spruce samples by Bekhta and Niemz [17].

It seems that surface quality of the sample improved due to the effect of heat treatment and compression. Control samples had an average R_a value of 4.67 µm which 8.3% higher than that of exposed to a temperature of 190 °C as shown in Fig. 3. Various studies revealed that surface roughness of veneer samples improved as a result of compression [17,23,24]. Although surface quality of treated samples in this work did not substantially enhance, heat treatment with combination of compression has still some benefits regarding limited surface quality improvement of the samples. These benefits include using less amount of finishing material and less sanding for further manufacturing steps which will result in reduction of overall production cost. It appears that smoother surface quality of the specimen was due to densification of compression and heat treatment. However such smooth surface did not create a good bonding between two samples reducing their strength values. Fig. 2 depicts typical roughness profiles of heat treated samples.

It has been clearly stated in literature the strength properties of wood adversely influenced by heat treatment due to thermal degradation. This loss becomes more prominent if temperature and exposure time are increased. It is a well known fact that polymers in the cellwall are depolymerized resulting in strength reduction of hemicellulose [19]. Esteves et al. determined different strength properties of pine and eucalyptus species reduced ranging from 15% to 40% due to heat treatment [23]. Heat treated spruce and pine also had lower strength properties within the range of 5–49% as a result of heat treatment [15].

Average hardness value of control specimen was 534 kg with decreasing values of 25.5% 34.6% and 59.9% as a result of heat exposures of 120 °C, 160 °C, 190 °C, respectively as illustrated in Fig. 5. In a past study determined the hardness values determined cross section, radial and tangential section of the of heat treated hazelnut wood samples had 44.94%, 62.32%, and 64.23% reduction due to expose to a temperature of 180 °C for 6 h, respectively [14]. The findings in this work agree with those determined above study.

4. Conclusions

In this work shear strength, hardness, and surface quality of compressed Eastern redcedar samples were evaluated as function of heat treatment. The lowest average reduction values in shear strength and hardness of the specimens was determined those exposed 120 °C. Overall surface roughness of the samples improved as a result of heat treatment suggesting that such samples would be easier to apply various coatings of finish requiring less amount so that overall production cost can be reduced. It appears heat treatment of Eastern redcedar at lower temperatures did not show any significant reduction of shear strength and hardness of the specimens which can be possibly used as an alternative method to enhance dimensional stability of such species. Since it is known that heat treatment has positive effect on dimensional properties of wood shrinkage and swelling of heat treated Eastern redcedar should be considered to be investigated in further phase of this work to have a better understanding of hygroscopic behavior of this species.

References

[1] Dilik T, Dündar T, Kurtoglu A, Hiziroglu S. Effect of adhesive types on some of the properties of laminated window profiles. J Mater Process Technol 2007;189:320–4.

[2] Follrich J, Muller U, Gindl W. Effects of thermal modification on the adhesion between spruce wood (*Picea abies* Karst.) and a thermoplastic polymer. Holz als Roh- und Werkstoff 2006;64:373–6.

[3] Kasemsiri P, Hiziroglu S, Rimdusit S. Characterization of heat treated eastern redcedar (*Juniperus virginiana* L.). J Mater Process Technol 2012;212(6):1324–30.

[4] Kocaefe D, Poncsak S, Boluk Y. Effect of thermal treatment on the chemical composition and mechanical properties of birch and aspen. BioResources 2008;3(2):517–37.

[5] Anonymous. Thermowood handbook, Finnish Thermowood Association, c/o Wood Focus Oy, P.O. Box 284, Snellmaninkatu 13, FIN-00171 Helsinki, Finland; 2003.

[6] Boonstra MJ, Tjeerdsma BF, Groeneveld HC. Thermal modification of non-durable wood species. Part 1 – the Plato technology: thermal modification of wood. International research group on wood preservation document no. IRG/WP 98-40123; 1998.

[7] Kocaefe D, Shi JL, Yang DQ, Bouazara M. Mechanical properties, dimensional stability and mold resistance of heat treated jack pine and aspen. Forest Prod J 2008;58(6):88–93.

[8] Militz H. Thermal treatment of wood: European processes and their background. IRG/WP 02-40241. In: 33rd Annual meeting, May 12–17, Cardiff-Wales 4; 2002. p. 1–17.

[9] Rusche H. Thermal degradation of wood at temperatures up to 200 °C. Part1: Strength properties of dried wood after heat treatment. Holz Roh Werkstoff 1973;31(7):273–81.

[10] Mummery L. Surface texture analysis: the handbook. Muhlhausen, Germany: Hommelwerke; 1993. p. 106.

[11] Poncsak S, Kocaefe D, Bouazara M, Pichette A. Effect of high temperature treatment on the mechanical properties of birch (*Betula papyrifera*). Wood Sci Technol 2006;40:647–68.

[12] Syrjanen T, Oy K. Production and classification of heat-treated wood in Finland review on heat treatments of wood. In: Proceedings of the special seminar held in Antibes, France; 2001.

[13] Sernek M, Boonstra M, Pizzi A, Despres A, Gerardin P. Bonding performance of heat treated wood with structural adhesives. European J Wood Wood Prod 2008;66(3):163–242.

[14] Korkut D, Korkut S, Bekar I, Budakçı M, Dilik T, Çakıcıer N. The effects of heat treatment on the physical properties and Surface Raughness of Turkish Hazel (*Corylus colurna* L.) wood. Int J Mol Sci 2008;9:1772–83.

[15] Korkut D, Korkut S, Dilik T. Effect of heat treatment on some mechanical properties of laminated window profiles manufactured using two types of adhesives. Int J Mol Sci 2008;9:454–63.

[16] Hiziroglu S, Holcomb R, Wu Q. Manufacturing particleboard from eastern redcedar. Forest Prod J 2002;52(7/8):72–6.

[17] Bekhta P, Niemz P. Effect of high temperature on the change in colour, dimensional stability and mechanical properties of spruce wood. Holzforschung 2003;57:539–46.

[18] Giebeler E. Dimensional stabilization of wood by moisture–heat–pressure-treatment. Holz als Roh-und Werkstoff 1983;41(3):87–94.

[19] Inoue M, Norimoto M, Tanahashi M, Rowell RM. Steam or heat fixation of compressed wood. Wood Fiber Sci 1993;25(3):224–35.

[20] Wood Handbook Forest Products Laboratory. Wood handbook—wood as an engineering material general technical report FPL-GTR-190. Madison, WI; US Department of Agriculture, Forest Service, Forest Products Laboratory, 2010. p. 508.

[21] Hiziroglu S, Graham S. Effect of press closing time and target thickness on surface roughness of particle board. Forest Prod J 1998;48:50–4.

[22] Hiziroglu S. Surface roughness analysis of wood composites: a stylus method. Forest Prod J 1996;46(7/8):67–72.

[23] Esteves B, Marques AV, Domingos I, Pereira H. Influence of steam heating on the properties of pine (*Pinus pinaster*) and eucalypt (*Eucalyptus globulus*) wood. Wood Sci Technol 2007;41(3):193–207.

[24] Candan Z, Hiziroglu S, McDonald A. Surface quality of thermally compressed Douglas fir veneer. J Mater Des 2010;31(7):3574–7.